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DAMAGE TO DEEP WELLS BY SEA WATER¹

By W. P. MASON²

Those who are familiar with the geography of Long Island, N. Y., will recall that an "inside water-way" extends almost completely along the Southern coast so that a boat of reasonable draft could sail easterly from Great South Bay nearly the entire length of the South shore without being exposed to the surf, and then, by means of a short canal already built, could enter Peconic Bay and finish the trip to the end of the island. Were it not for the presence of a narrow neck of land immediately to the east of Jamaica Bay the start could be made from within the limits of the City of Brooklyn.

It has been proposed to cut through this said neck by means of a canal 100 feet wide and 12 feet deep, thus completing the waterway. The construction of such a canal, if built, would be undertaken by the Federal Government and the necessary land, together with the bridges over the canal, would be furnished by the State of New York.

Several routes for the proposed work were considered, which naturally presented varying costs and engineering difficulties, the former embracing damages to private properties. Among the properties for which damages might be claimed are the wells of the Queens County Water Company which are so situated as to be within comparatively short distances of two of the contemplated sites of the canal, and, as the channel would carry salt water, the question presented was would the admitted sea water damage the public water supply derived from the wells.

It was proposed that the canal should run for a considerable distance in a straight line through territory adjacent to the pumping plant of the Queens County Water Company and within 50 feet of the nearest well; or else that it should pass through a district further to the south where, by means of a wide bend, it would pass the nearest well of the Company at a distance of about 1000 feet, as shown in figure 1.

¹ Read before the Montreal Convention, June 24, 1920. Discussion is invited, and should be sent to the Editor.

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The soil of the District is practically a pure sand of about 0.23 effective size and 1.69 uniformity coefficient.³ The top layer is tillable and adapted to the growing of crops, but the level corresponding with the bottom of the canal is simply sand.

The southern portion of Long Island, as is well known, consists of various strata of sands and gravels, more or less distinct, and, at differing depths, separated by discontinuous layers of clay. These strata are water-bearing and dip towards the south so that artesian developments are possible along the southern coast.

The source of this sub-surface water is the rain which falls upon the island itself, the precipitation being about 44 inches per year. Because of the sandy character of the soil the percentage of percola-

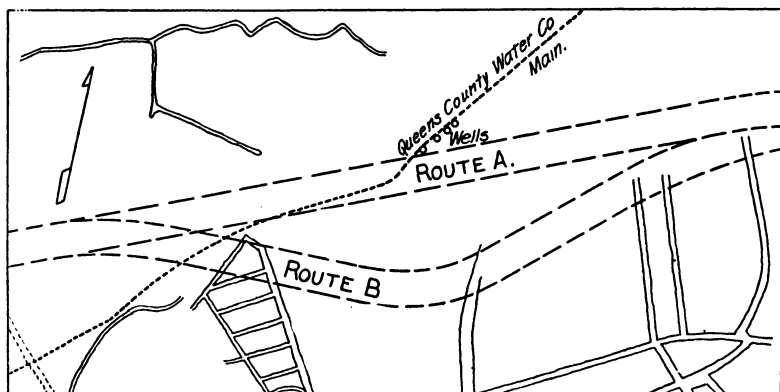


FIG. 1. RELATION OF ALTERNATIVE CANAL ROUTES TO WELLS OF QUEENS COUNTY WATER COMPANY

tion is very high, 42 per cent according to Burr, Hering and Freeman, and the amount of run-off correspondingly small, conditions which greatly aid the volume of underground flow.

The back-bone of the island not being of much height, the wells that have been sunk to the lower gravel layers flow at only moderate elevations above the ground surface and it is therefore common practice to secure their water by pumping.

The water-table, or surface of the underflow, slopes southward at about 10 feet per mile, as shown in figure 2, and the rate of water movement at a distance of about one mile from the sea may be

³ See table by G. C. Whipple in Report on Additional Water Supply of New York by Burr, Hering and Freeman, page 580.

placed at approximately 30 feet per day or 2 miles per year.⁴ This rate of movement is really quite variable. The results obtained experimentally by Prof. C. S. Slichter showed values of from 2 to 96 feet per day.⁵

The Queens County Water Company takes this underflow by a group of wells, 50 of which are 165 to 208 feet deep and 70 others with a depth of 30 to 45 feet. The deep wells pass through a layer of clay from 20 to 40 feet in thickness. The water is raised by pumps, aerated, filtered to remove the excess of iron and is then pumped to a standpipe, whence it flows to the consumers.

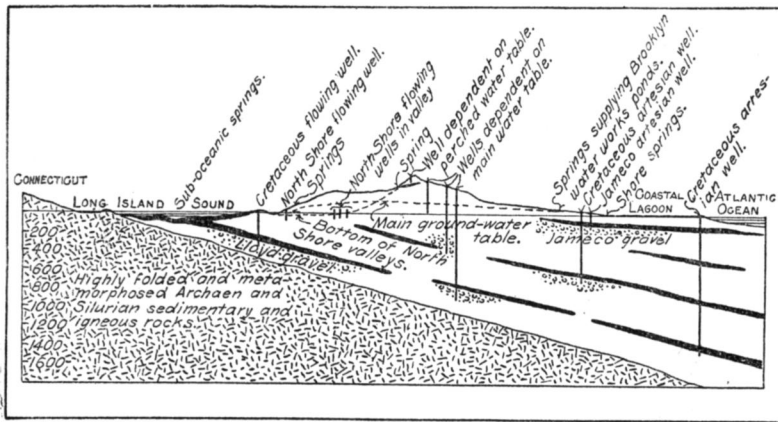


FIG. 2. DIAGRAMMATIC CROSS-SECTION OF LONG ISLAND, SHOWING CAUSE OF FLOWING WELLS

The quality of the water so delivered is excellent, as is shown by the analyses on file. In fact it may be considered a "normal" water, low in chlorine, hardness, alkalinity and total solids.

The action of driven wells such as used by the Water Company, when coupled up with powerful pumps, causes a material lowering of the ground water in the immediate vicinity of each well and the slope of its surface or "water table" becomes steeper as the well is approached, until it assumes the form of an inverted cone whose apex is at or near the bottom of the well. The slope of this conical depression in the water table, or the "cone of influence," as it is termed, becomes less steep as the distance from the well increases

⁴ Reisert vs. New York City.

⁵ Professional Paper 44, U. S. Geological Survey, page 104.

until it finally shades off to zero and merges into the general level of the ground water of the district.

The area that the "cone of influence" represents on the surface of the ground, that is, the area of its base, will depend upon the volume of pumpage compared with that of the underground flow and upon the frictional resistance presented by the material comprising the water-bearing stratum.

The drift of the ground water being towards the south and the Queens County wells being located north of both of the proposed canal sites, no natural flow of sea water towards the wells could be expected and the only explanation of its presence in the well water, should it make its appearance there, would of necessity point to an extension of the "cone of influence" sufficiently far to include at least one bank of the canal.

The tightness of the canal bottom might be suggested as a preventive of salt water passing through it to the damage of the ground water on the north, it being long known that "perched" ponds and streams are frequently found to leak but little; it must be remembered, however, that the canal would be of new construction, dredged through clean sand and therefore there would be but small opportunity for any silting action to close the porous material of its bottom.

Wells near the sea-shore are widely employed to furnish potable water but the first rule connected with their use is to carefully keep the volume of their delivery safely within the limit of their natural reinforcement. Both Liverpool, England, and Galveston, Texas, it will be remembered, pushed the pumpage on their wells beyond the margin of safety with the result that sea water was drawn into their systems in damaging quantities.

Does the southerly limit of the Queens County "cone of influence" reach 1000 feet from the wells; that is, does it extend far enough to include the more southerly of the two suggested sites for the canal?

This is a very important question and is bound up with the inquiry "Would the wells draw salt water in the event of the canal being built?" As lending light upon this matter it is wise to examine into the effect of heavy pumping upon the composition of the waters of sundry wells sunk in nearby parts of Long Island. The chemical data in the following tables are given in parts per million, and they, together with the pumpage, are the averages for the years in ques-

tion. The distances of the wells from the nearest tidal streams are given in feet.

The list of well waters here following could be materially extended but enough are given to illustrate general conditions. Many of the data here used have been derived from the records of the Water Department of New York City and from government publications.

Increase of chlorine in wells at Agawam. Depth of wells, 33 to 91 feet. Distance from tidal stream, 2000 feet

DATE	CHLORINE	HARDNESS	NITRATES	TOTAL SOLIDS	DAILY PUMPAGE
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	million gallons
1898	5.7	7.2	0.04	33	0.3
1899	5.2	6.7	0.17	33	0.5
1900	5.1	8.0	0.19	34	1.3
1901	4.9	10.2	0.17	38	1.4
1902	4.3	10.2	0.06	30	0.6
1903	3.9	8.3	0.01	33	0.1
1904	4.2	7.9	0.00	27	0.2
1905	4.7	13.0	0.30	45	1.3
1906	4.8	9.0	0.41	47	1.8
1907	5.0	12.0	0.43	51	1.2
1908	4.6	8.0	0.18	40	1.1
1909	5.2	14.0	0.70	46	2.4
1910	9.5	18.0	0.63	59	2.8
1911	19.3	20.0	0.53	73	2.7
1912	9.1	22.0	0.45	68	3.3
1913	14.8	18.0	0.46	72	4.0
1914	32.7	25.0	0.49	110	4.1
1915	61.0	35.0	0.63	157	4.8
1916	62.2	33.0	0.65	158	4.6

This table shows by the increase of chlorine, hardness and total solids a draft of sea water due to increased pumpage.

Increase of chlorine in wells at New Brighton. Distance from tidal stream, 1200 feet

DATE	CHLORINE	HARDNESS	NITRATES	TOTAL SOLIDS	DAILY PUMPAGE
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	million gallons
1903	107	166	2.50	382	
1904	104	191	3.35	421	
1905	160	228	2.84	526	
1906	115	190	3.14	436	
1907	244	271	3.44	761	
1908	225	281	5.12	718	
1909	372	376	2.51	1022	
1910	580	496	2.39	1436	3.3
1911	454	413	2.01	1215	3.4
1912	482	428	1.27	1298	3.6
1913	518	429	1.18	1347	3.4
1914	419	341	1.37	1090	3.4
1915	406	325	1.27	1028	2.5

The influence of the sea was manifest at the start but it increased by the operation of the pumps.

Increase in chlorine in wells at She-tucket. Depth of wells, 180 feet. Distance from tidal stream, 1500 feet

DATE	CHLORINE	HARDNESS	NITRATES	TOTAL SOLIDS	DAILY PUMPAGE
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	million gallons
1897	4.3				0.0
1898	25.7	107	0.03	189	3.0
1899	185.0	164	0.00	534	1.7
1900	288.0	243	0.00	762	1.2
1901	388.6	324	0.00	987	1.4
1902	433.7	360	0.01	1096	1.0
1903	281.8	227	0.02	623	0.4
1904	280.6	249	0.03	728	0.5
1905	174.6	208	0.01	437	0.2

The wells pass through the clay stratum and the sea water probably enters from underneath that layer.

Increase in chlorine in wells at New Utrecht. Depth of wells, 30 feet. Distance from tidal stream, 5000 feet

DATE	CHLORINE	HARDNESS	NITRATES	TOTAL SOLIDS	DAILY PUMPAGE
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	million gallons
1898	21.1	90	2.48	156	1.1
1899	21.2	88	3.24	144	1.1
1900	67.4	136	2.84	254	2.0
1901	123.0	186	2.88	398	1.8
1902	88.0	144	4.13	324	1.5
1903	76.4	136	3.12	273	1.4
1904	90.6	141	2.93	342	1.9
1905	102.8	164	3.17	354	1.9
1906	97.5	178	3.22	341	1.6
1907	106.6	170	3.17	362	1.6
1908	151.0	176	3.15	463	1.1
1909	163.4	207	3.36	521	1.1
1910	239.4	265	2.00	675	0.2

Influence of salt water was shown at the start and rapidly increased.

Increase in chlorine in wells at Woodhaven. Depth of wells, 80 to 150 feet. Distance from tidal stream, 2000 feet

DATE	CHLORINE	HARDNESS	NITRATES	TOTAL SOLIDS	DAILY PUMPAGE
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	million gallons
1908	9.7	85	6.58	181	3.1
1909	11.3	88	7.13	177	3.1
1910	12.5	102	7.90	190	3.3
1911	15.8	106	6.90	206	3.3
1912	22.3	114	6.00	211	3.1
1913	52.3	159	6.25	306	3.5
1914	142.0	272	4.40	511	3.6
1915	223.0	290	3.44	647	3.4

Influence of the sea rapidly developed with small change in pumpage.

Increase in chlorine in mixed filtered water supplied by Queens County Water Company

DATE	CHLORINE	HARDNESS	NITRATES	TOTAL SOLIDS
	p.p.m.	p.p.m.	p.p.m.	p.p.m.
1899	3.7	12	0.00	33
1900	3.4	16	0.00	38
1901	3.2	15	0.00	41
1902	3.4	13	0.00	44
1903	3.6	12	0.02	42
1904	4.1	20	0.02	47
1905	4.1	13	0.01	43
1906	4.4	11	0.06	46
1907	3.9	12	0.07	53
1908	4.2	14	0.05	50
1909	4.9	16	0.17	55
1910	4.6	15	0.08	52
1911	4.9	17	0.12	57
1912	4.4	16	0.09	50
1913	3.9	13	0.07	49
1914	4.8	15	0.05	59
1915	4.8	18	0.10	54

Increase in chlorine in wells of Queens County Water Company. Unfiltered water. A mixture from both deep (165 to 208 feet) and shallow (30 to 45 feet) wells. Distance from tidal stream, 2500 feet

DATE	CHLORINE	HARDNESS	NITRATES	TOTAL SOLIDS	DAILY PUMPAGE
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	million gallons
1899	3.7	17	0.02	37	
1900	3.2	13	0.01	44	
1901	3.2	16	0.01	50	
1902	3.4	16	0.01	48	
1903	4.2	12	0.07	45	
1904	4.2	23	0.05	52	0.3
1905	4.4	13	0.03	49	3.1
1906	4.3	11	0.10	49	3.6
1907	4.0	13	0.13	53	3.2
1908	4.2	15	0.13	59	3.1
1909	5.1	17	0.19	62	3.9
1910	4.6	16	0.17	58	7.1
1911	4.9	17	0.16	61	5.8
1912	4.3	15	0.12	54	4.3
1913	3.9	14	0.09	54	3.9
1914	4.2	16	0.12	54	3.4
1915	5.0	16	0.13	58	2.4

No material change in composition of the water.

Increase in chlorine in wells at Jameco. Depth of wells, 160 feet. Distance from tidal stream, 2000 feet

DATE	CHLORINE	HARDNESS	NITRATES	TOTAL SOLIDS	DAILY PUMPAGE
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	million gallons
1898	5.5	78	0.01	117	5.2
1899	5.0	82	0.00	121	4.9
1900	4.7	90	0.01	123	4.9
1901	4.5	98	0.00	120	5.2
1902	4.5	92	0.01	126	3.7
1903	5.2	93	0.01	122	3.9
1904	4.3	87	0.03	125	3.8
1905	4.3	87	0.00	123	3.3
1906	4.8	71	0.04	116	5.1
1907	4.8	75	0.07	115	7.7
1908	5.5	69	0.05	123	7.8
1909	5.0	72	0.01	118	6.7
1910	4.5	82	0.04	127	9.1
1911	4.4	89	0.04	131	7.8
1912	4.8	92	0.10	134	8.6
1913	6.8	76	0.07	127	8.1
1914	13.9	79	0.06	138	8.1
1915	17.1	70	0.07	137	7.2

Influence of the sea very slow in developing.

Increase in chlorine in wells at Grant City, Staten Island. Distance from tidal stream, 3000 feet

DATE	CHLORINE	HARDNESS	NITRATES	TOTAL SOLIDS	DAILY PUMPAGE
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	million gallons
1905	7.7	138	3.21	166	
1906	9.0	135	2.64	172	
1907	20.9	158	2.67	219	
1908	15.5	127	1.71	201	
1909	54.5	160	1.52	262	
1910	139.9	246	1.48	466	1.7
1911	119.9	216	1.31	433	1.7
1912	116.3	206	1.03	426	1.9
1913	150.0	228	1.18	504	2.0
1914	162.0	243	1.16	523	1.9
1915	348.0	404	1.27	946	4.6

The 1915 pumpage includes that of the driven wells on Southfield Boulevard. Although the rate has been fairly constant (omitting that of 1915) sea water has been drawn into the wells, and as a result the chlorine shows very high. The water was served to the people without dilution, as no surface or other water was available to mix with it. It is interesting to note that when the Catskill water was turned on the people complained of its taste, having been used to hard water in the past. Very recently, because of a threatened shortage of the Catskill supply, the former well water was once more put in use; again there was complaint because of the taste.

Increase in chlorine in wells at Gravesend. Depth of wells, 50 feet

DATE	CHLORINE	HARDNESS	NITRATES	TOTAL SOLIDS	DAILY PUMPAGE
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	million gallons
1898	12.8	91	3.44	151	2.5
1899	12.7	92	3.68	150	2.4
1900	13.3	101	3.98	158	2.9
1901	13.5	88	4.63	152	3.0
1902	13.4	94	4.50	156	2.9
1903	14.5	99	4.00	168	2.8
1904	14.0	97	3.58	169	2.9
1905	14.9	91	3.99	177	3.0
1906	16.6	100	3.90	173	2.9
1907	17.6	99	4.24	182	3.2
1908	15.8	101	3.73	192	3.2
1909	24.4	107	4.32	192	4.4
1910	42.0	133	5.05	241	5.4
1911	77.9	170	3.65	343	5.0
1912	99.9	201	3.30	366	4.7
1913	97.4	201	3.00	389	4.2
1914	213.3	343	2.86	662	4.8
1915	171.3	285	2.90	665	3.3

The influence of the sea was not so quickly felt doubtless because of the considerable distance to salt water but it nevertheless was manifest after a time. High as the chlorine finally became, those people who lived in the vicinity of the plant received it without dilution.

Leaving for a moment the ordinary form of well, it will be of interest to extend the inquiry to include the infiltration gallery situated at Wantagh. This gallery consists of a line of 20-inch and 36-inch pipe laid with open joints and from it the water collected is pumped to the consumers. Test wells were sunk at varying distances in a line at right angles to the gallery so that the effect of

pumping upon the height of the ground water might be observed. The effect of the gallery in lowering the ground-water level was felt at a distance of about 2900 feet.

As a further demonstration of the tendency of the gallery to lower the underground water level of the neighborhood, the records show that Jackson Jones pond, which is situated at a distance of 1500 feet to the south, was drained practically dry during the pumping period but, as the author personally observed, it has filled again since the pumps were stopped. It is important to note that this pond is an old one with a heavily silted bottom, consequently much more "water-tight" than a new canal dug in the sand would be.

To return to the well data already given, it will be observed that the Queens County Water Company wells have not materially changed in the character of the water delivered by them during the entire length of their service and it will also be noted that the quality of the water is excellent.

The water of the Agawam wells shows by its increase of chlorine, hardness and total solids that a draft of sea water has followed an increase of pumpage. The actual amount of the inflow of salt water is small compared with the record of other wells but the relation to an enlarged volume of pumpage is noteworthy.

Several points of interest are apparent when the tables are carefully inspected. Thus a pronounced "lag" is observed between some pumping records and the chemical changes in the water that the pumping is supposed to have produced. Again it is seen that a low pumpage may be productive of a great chemical change, as at New Utrecht, while a high pumpage may require a long period to establish material alteration in the amount of salines present in the water, as at Jameco.

At Shetucket, figure 3, it would appear that after heavy pumping had inaugurated an inflow of sea water, the quantity of such flow steadily and largely increased even after the volume of pumpage was progressively diminished.

So it would seem to be a fact that small information can be secured by attempting to closely correlate the pumpage with the analytical curves, and we are obliged to rest satisfied with the observation that only the general records for a period of years are important and their tendency is to show that pumping many of these Long Island wells is sooner or later followed by an infiltration of sea water, as indicated by increase of the salines.

How far the area of influence of the Queens County Water Company's wells extends towards the south it would be only guesswork to say, but from what we have learned by a study of other nearby wells the author would put 1000 feet as well within the probable limit and that is the distance from the Queens County pumping plant to the site of route B proposed for the canal. Site A is very much nearer, being only 50 feet from the wells.

In view of sand being such an admirable medium for filtration purposes, it was suggested that so long a distance as "1000 feet would be ample to provide for the removal of polluting material;"

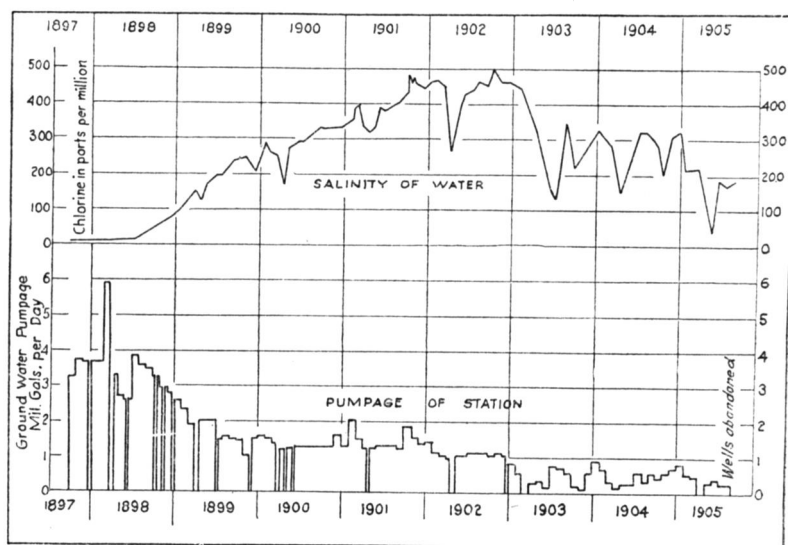


FIG. 3. SALINITY OF GROUND WATER PUMPED AT SHETUCKET DRIVEN WELL STATION

but the great difference must be borne in mind between sea water and organic pollution. The salines present in the former are in solution and are **not** decomposable by such processes as oxidation and nitrification. Common salt, the large item in sea water, will undergo any amount of sand filtering without practical change in quantity.

Fresh water is often to be found in the sands of the seashore and leads to the impression among some people that its source is the sea, the salt having been removed by a process of sand filtration; whereas the fact is that such water is from the land and is caught

on its way to the ocean. An interesting case may be observed at Heligoland, where, on a little islet near the main island, a well furnishes drinking water for the small population although the well is sunk only a few feet into the sand of an area two or three hundred feet wide and as many yards long. The reason for the fresh water being there is because its relative lightness allows of its floating for a time on the heavier sea water saturating the sand bar and rainfall is sufficiently frequent to replenish it before diffusion carries it into the body of the salt water below.

Common salt is represented in water analysis by chlorine and is one of the measures indicating sewage pollution. When it is known to be derived from sea water it is looked upon with less suspicion and the question then resolves itself into how high may the chlorine run without objection? Such a question is difficult to answer, because, under the circumstances, the chlorine is not an indicator of the presence of another agent far more dangerous than itself but is to be judged entirely upon its own merits or demerits, associated of course with the other mineral constituents of sea water. Taste is somewhat of a guide, although a rough one. Some people are capable of detecting the presence of ocean water when mixed with fresh in an amount equivalent to 100 parts of chlorine per million. This is not due to the taste of the common salt alone but to the combined effect of it and the other associated mineral salts. About ten times that quantity of sodium chloride in distilled water would be required to produce taste.

Standards whereby to classify waters are usually rather risky propositions to advance, but for tentative purposes the suggestion may be admissible to place 50 parts per million of chlorine, derived from sea water, as a suitable upper limit and twice that quantity as the amount not to be passed.

Hardness as well as chlorides will increase with admission of sea water, so that complaint against the water is more likely to originate among industrial users than from the sanitary side.

Under the supposition that the route B was chosen and the canal was constructed on that site, which is 1000 feet to the south of the Queens County Wells, the question might be asked, "How long before ocean water would begin to be noticeable in the water of the wells and how long before it would reach an amount sufficiently high to cause objection, of course assuming the pumpage to be fairly constant and at its present volume?"

Having in mind the tentative chlorine number mentioned above and referring to the tables already given we find that sea water represented by chlorine of about 50 parts per million manifested itself after the following periods, dating from the time of starting the pumps.

PLACE	PERIOD	DISTANCE TO SEA WATER	REMARKS
	<i>years</i>	<i>feet</i>	
Agawam.....	16	2000	Pumpage increased
Grant City.....	4	3000	
Shetucket.....	2	1500	
Gravesend.....	12		
New Utrecht.....	2	5000	Chlorine still under 20
Jameco.....	17	2000	
Woodhaven.....	5	2000	

Availing ourselves of the data given, it would seem a safe statement to make that a period of some years would elapse before sea water could reach the Queens County Water Company wells if the canal were constructed along route B, but it would be unsafe to venture an explicit prediction of the exact length of time "some years" might mean. It seems most likely that the influence of the canal water would be felt first, if not exclusively, by the shallow wells, for the reason that the deep ones pass through a layer of more or less protective clay; nevertheless we do not accurately know where the breaks, if any, in the continuity of the clay may be.

Sooner or later salt water would reach at least a portion of the wells of the Queens County Water Company if the canal were built on route B. Should it be dredged along route A, namely, within 50 feet of the Queens County Water Company plant, the adverse effect upon the water of the wells would be immediate.

Examination of the data here given points to the discouraging conclusion that if wells be once contaminated by sea water through overpumping, the damage cannot be readily repaired by stopping the pumps but is likely to be permanent. Several of the tables of results show that to be a fact, especially the one dealing with the plant at Shetucket.

This is graphically shown in figure 3 by W. E. Spear,⁶ the salinity curve starting near the zero line under a pumpage of about 6,000,000

⁶ Long Island Sources of Water Supply, volume 1, page 146.

gallons per day and persistently rising during the following years until it touched 500 parts per million although the pumpage during the period was rapidly lessened to about one-sixth of its original volume.

As to the spacing of wells so as to collect the maximum amount of the southward flow of the ground water of Long Island and at the same time avoid damage of drawing sea water into the system, the author cannot do better than quote⁷ Mr. Spear's words:

It appears preferable, under conditions that exist in southern Long Island, to intercept the ground-water by means of a continuous line of wells at frequent intervals along the proposed aqueduct line, rather than by groups of wells at stations one to two miles apart.

In order that no water may escape to the sea between the groups of wells, the ground-water surface and the deep pressure gradient must, at every point on the line of the collecting works, be inflected away from the ocean towards the wells. The greater lowering of the ground-water near the groups of wells to effect this result is evident. Aside from the danger of drawing in salt water in pumping deeply at each group of wells, the greater efficiency of the pumps at the central stations is likely to be more than offset by the greater lift required by the greater depression of the water-table that is necessary at the central pumping-station.

DISCUSSION

WILLIAM GORE: The speaker would refer to the case of injury some twenty-five years ago to a deep well by sea water at Eastbourne. This well was sunk into the chalk (an amorphous kind of limestone) some distance back from the cliffs at the edge of the sea on the south coast of England. The well was the property of the water company supplying water to Eastbourne and had for many years yielded a water of excellent quality practically free from salt, when suddenly it became highly charged with salt, due to the access of sea water.

In the course of twelve months the salt reached to some two thousand parts per million. The company attempted to cut off the salt by closing an adit from which the salt appeared to have come, but without much success, and as the town was largely dependent on this well, salt water was continued to be supplied.

As the town of Eastbourne is a seaside summer resort, the condition of the water drove visitors away and caused a considerable loss to the citizens. For this reason, as there did not appear to be

⁷ Long Island Sources of Water Supply, volume 1, page 186.

any sufficient action on the part of the company to seek new sources the municipal corporation proceeded to parliament to get a new water supply independent of the company and to sequester the company's distribution works. This proposal was, however, defeated, probably due to the promise of the company that it would proceed at once with new works at a greater distance from the sea so that the salt water well would be abandoned at an early date.

The sudden entrance of sea water after many years yielding of pure water caused some discussion. It was thought that when a well became salt by drawing in sea water the rise in the salt would be fairly gradual, dependent, of course, upon rainfall and pumping. A theory put forward which appears to have a high degree of probability was that the chalk contained quantities of natural zeolites which absorbed the salt until saturated, and while the well had actually been drawing sea water for years, this sea water had been purified by the natural zeolites in the same way as zeolites used in water-softening processes are regenerated by the application of a salt solution.

H. F. DUNHAM: One condition or feature has not been closely touched upon or set out. The Long Island and adjacent Atlantic shores are far from abrupt and in most localities quite flat and in some cases there are ridges of sand above ordinary high tide or high water while back of those elevations or ridges there are quite large areas that are but little above mean high water. Now when an exceptionally heavy storm occurs, the low areas are flooded with salt water, which may be confined or landlocked there for some time because of the wave action in washing up new ridges or adding to low places in old ones. In this way salt water may be held in the vicinity of wells that are comparatively quite distant from the shore, and unless there is an impervious bed of clay or other layer the effect of the salt water invasion will be noticed.

The Grant City wells referred to were installed under the direction of the speaker about half a mile from the shore line, but nearer shore a test or sample well was sunk to the same depth as the others and used to show the increase of chlorine due to any exceptional behavior of the Atlantic or to a heavy draft upon the wells in dry seasons. The Crystal Water Company had at that time two sources of supply, one on much higher ground, and one of them could be favored a little for a time at the expense of the other.

The Massachusetts Board of Health has shown, the speaker believes, that all ground water near the ocean carries an extra incre-

ment of chlorine. There are interesting figures in the reports of that board from the Swampscott Water Supply. The monthly examinations were compared and a danger or salt line suggested if not established.

Doubtless it would be impossible to find an entire absence of chlorine in a well that had been invaded by salt water but the speaker believes a heavy annual rainfall would do much toward restoring conditions after heavy storms or unusual draft upon the ground water and also that a number of "wet" years after dry years would help restore or improve the average quality of the supply.

So far as taste of water is concerned, it might be mentioned that years ago a water works superintendent in an Illinois city drank at the town pump and said the water made him ill for three days. Analysis of the water by a member of this Association showed chlorine about 1800 parts per million. Phone message to State Board of Health. Well filled up after finding that the "strainer" was about 6 feet below and but a few feet away from a newly made brick sewer. But the people who had been using that sickening well-water not only protested but were decidedly angry for weeks because their "right to use that sweet water had been interfered with." This Association has derived some advantage from its devotion to standards, no doubt, and it has also suffered and continues to suffer from that same devotion. But when it comes to establishing standards for taste it might be well to first specify a standard stomach.

LEONARD METCALF: It seems that a few words of caution, in which the author will probably agree, are desirable in connection with any standard chlorine content of water. The author's problem was a water supply for persons accustomed to water without taste. The speaker knows, however, of several cases where the practical limit of salinity, to which water could approach without causing complaints, was between 300 and 400 parts per million. When that limit was exceeded, the saline water had to be diluted in order to keep the supply acceptable.

There are cases of recovery in the quality of water from wells. The speaker knows of some cases where the salinity of well water increased from a very low figure to several hundred parts and, eventually, to 900 parts per million. For example, the limit of permissible salinity at Tampa is about 350 parts, but during times of heavy demand it is practicable to make use of water containing

considerably more salt by diluting it with less saline water until the average salinity of the mixed supply is below the maximum limit. It has been found there that if a well yielding very saline water is kept out of commission for a year or two, the salinity, decreased. The salinity does not disappear, because recovery is a very slow action and its rate depends to some extent on the quantity of water available.

RUDOLPH HERING: A year ago last winter salinity caused serious trouble in the water supply of Miami, Fla. Most of the supply comes from deep wells, but sometimes part of the supply is taken from shallow wells with the water level 25 to 30 feet below the surface. As the city was growing rapidly and there were not enough wells to meet the maximum draft without pulling on them heavily, salt water was drawn into the wells in such quantities that the supply became undrinkable and was used only for washing, flushing and like purposes. The cone of depression due to the heavy pumping extended beyond the shore line.

One main reason for the heavy draft was the heavy leakage from a large street main. During the summer this main was repaired, which reduced the pumpage greatly, and last winter the water drawn from the same wells was free from a saline taste.

CHESTER R. McFARLAND: In regard to previous remarks about conditions at Tampa, it must be acknowledged that the Tampa Water Works Company has had a variety of experiences with salinity of water. The company had one well which was in use for 15 years, sometimes flowing under a natural head of 12 to 15 feet above sea level and sometimes pumped by compressed air. The salinity of the water from this well has varied greatly. At the beginning of operations it was around 21 parts per million. It has risen as high as 600 parts and then dropped to less than 100 parts, so that there has been no regularity in the curve of salinity.

Furthermore, salinity in the ground water is not at all uniform in the district where this well is located. One well may furnish water of very low salinity and another well sunk within, say, 700 feet, may furnish water with 2000 parts of salinity. One well may supply good drinking water and another close by, sunk to the same depth, may supply brine. In some cases resting will decrease the salinity, but not always. One of the interesting features of the salinity of the water in these wells is that the proportions of different salts is not the same as that of the salts in sea water.